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THERMALLY-INDUCED UNSYMMETRIC OPTICAL DISTORTION
OF OUTPUT WINDOW OF HIGH-POWER CO_2 LASER

by

Chen Peifeng, Qiu Junlin, et al.

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THERMALLY-INDUCED UNSYMMETRIC OPTICAL DISTORTION OF OUTPUT WINDOW OF HIGH-POWER CO_2 LASER

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Abstract: Thermally-induced unsymmetric optical distortion of the output window of high-power CO_2 lasers has been investigated theoretically and experimentally. This kind of distortion could lead to resonator misalignment.

Key words: CO_2 laser, window, thermally-induced optical distortion

I. Introduction

There has been much research on thermally-induced optical distortion at the output window of high-power CO_2 laser devices. However, earlier studies were done on symmetric thermally-induced optical distortion of the optical axis as the central axis. Aspects of this kind of symmetric thermally-induced optical distortion include not changing the direction of the optical axis, but only possibly inducing parametric changes in the resonant cavity, and optical beam divergence. Hence, the symmetric thermally-induced optical distortion does not

supposedly induce misalignment of the optical cavity.

In addition to symmetric thermally-induced optical distortion as mentioned above, there is thermally-induced optical distortion of the unsymmetric output window in transverse-flow CO_2 laser devices as discovered in practical work. In addition to inducing variation in the cavity parameters and causing unsymmetric thermally-induced optical distortion as affecting the divergence of the output light beam, change of optical axis in the cavity may be induced, thus misaligning the optical cavity. Sometimes this misalignment is quite serious. In this paper, the discussion centers on misaligning the optical cavity caused by unsymmetric thermally-induced optical distortion. A separate paper will discuss unsymmetric thermally-induced optical distortion as affecting changes in the parameters of the resonant cavity and divergence of the output light-beam.

II. Analysis of Experiment

During the development of the high-power transverse-flow CO_2 laser, sometimes very serious misalignment may occur in the resonant cavity. An He-Ne laser was used to monitor changes in various regions of the optical cavity system as the laser device was being operated. Fig. 1 shows the experimental set-up.

With a certain angle Θ, the He-Ne laser beam is emitted incident onto the monitored portions (including areas of the output lens, reflective mirror, and optical bridge system), and is reflected at point O'. At point O', an optical screen receives the incident beam; record the position of point O'. Observe change of point O' throughout the experiment.

The authors discovered the following phenomena:

(1) The change in the output lens is quite distinct; the

change of the reflected light spots from the output lens is directly related to the output light power. In the experimental procedure, when the power fed to the laser device corresponded to 1.2kW in output power, and the reflective mirror was manually deviated so that the power was reduced to 200W, it was thus discovered that the monitored light spots on the output lens returned to their initial position. However, no change was discovered for other monitored light spots. This explains that deformation of the output lens is determined by the magnitude of output power. Refer to Fig. 2.

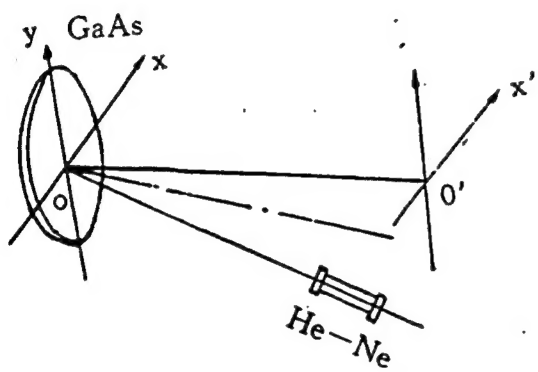

Fig. 1. Experimental set-up

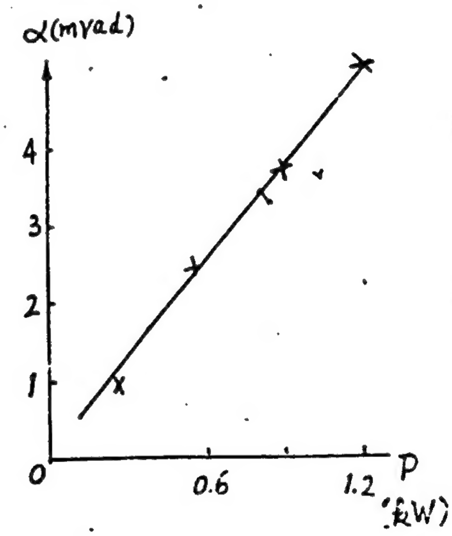

Fig. 2. Power and misalignment-angle curve

(2) The output power varies with the varying output-lens deformation. By adjusting the direction of the reflective mirror, the maximum power can be fully restored. This explains that the variation in output power is not due to the variation of the resonant-cavity parameters caused by distortion of the output lens but to maladjustment.

(3) Fig. 2 shows the measurement values of the output-lens deformation as a relation between the deformed angle α of the central point, and the output power P. By measuring the deformation of different points at the output lens, it can be discovered that the distortion is apparently unsymmetric.

(4) When lowering the output power, we can observe that the divergent angle of output light-beam apparently increases in the direction of output-lens deformation. This explains that the unsymmetric distortion will induce unsymmetric distortion of the divergence property.

In summing up these experimental results, we can observe that the maladjustment of the optical cavity is induced by the unsymmetric thermally-induced optical distortion of the output window, thus inducing very marked reduction in output power.

III. Theoretical Analysis

Thermally-induced optical distortion of the output window is caused by the laser beam power being absorbed. Thus, this is actually a problem of heat distribution. Assume that the margin of the output lens is in contact with the water cooling seat; in addition, the front and rear lens surfaces are in contact with the atmosphere and the sub-atmospheric-pressure gas in the laser device. The heat conduction of the gas is much smaller than that via cooling of the water at the lens edge. Therefore, it can be assumed that the front and rear surfaces are adiabatic surfaces. Then the temperature does not change in the Z-direction in Fig. 3. The three-dimensional heat conduction equation can be simplified into a two-dimensional problem.

$$\begin{cases} \nabla^2 T(x \cdot y) + q(x \cdot y)/k = 0 \\ q(x \cdot y) = \beta \cdot P \\ \text{T (cooling sleeve)} = T_\infty \end{cases}$$

In the equations, the origin of coordinates is selected at

the center of the optical axis; P is laser power density. Assume that the laser beam covers the entire lens, β is the absorption coefficient of the lens. Assume that the temperature of the cooling water sleeve is ; note down the temperature of the cooling water sleeve and the temperature distribution of the lens margin. The relation is associated with contact tightness the between lens margin and cooling water sleeve. With better contact, the temperatures are fairly close; with poor contact, however, the temperatures may differ widely.

As found in qualitative analysis, poor contact between lens and water-cooling sleeve will induce unsymmetric thermally-induced optical distortion, thus causing maladjustment of optical cavity. As shown in Fig. 4, assume that there is good contact between region A of the lens margin and the water-cooling sleeve; however, there is poor contact between region B and the water-cooling sleeve. Obviously, the temperature near region A is lower than the temperature near region B, thus causing deformation as shown with the dashed line in Fig. 4. Thus, maladjustment of the optical cavity occurs. By solving precisely for Eq. 1, a quantitative conclusion may be derived although this is relatively difficult. A brief analysis is made in the following text.

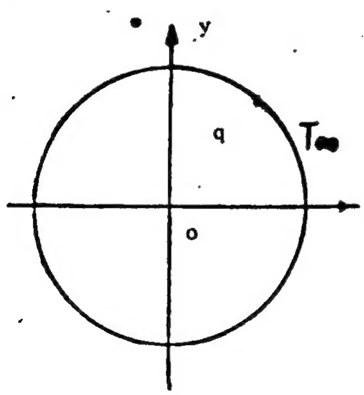

Fig. 3. Theoretical model for calculation

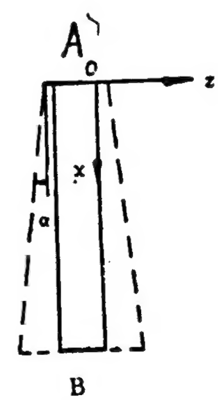

Fig. 4. Unsymmetric optical distortion

Obviously, if there is poor contact over a very small

region, this unsymmetric distortion can be neglected. Hence, it is significant only with poor contact over a large area. Thus, we assume that no contact occurs at one-half of the margin, while there is good contact over the other half. In other words, as shown in Fig. 4, heat conduction occurs in the upper half while there are adiabatic conditions in the lower portion. Furthermore, we assume that no contact occurs at half the margin while there is good contact at the other half. Furthermore, we assume that heat conduction in the Z- direction can be neglected, and then Eq. 1 can be simplified as an one-dimensional heat conduction equation [1].

$$\frac{d^2T}{dx^2} + q/k = 0$$

The solution is

$$T = -\frac{q}{2k} + c_1 x + c_2$$

The boundary condition is: $x = 0$ $\quad -k\frac{dT}{dx} = h_0(T_\infty - T)$

$x = 2R$ $\quad K\frac{dT}{dX} = 0$

In the equations, T_∞ is the temperature of the water-cooling sleeve; h_0 is the coefficient of thermal conductivity between the lens and the water-cooling sleeve; and R is the lens radius.

Assume q is a constant, then we have

$$T = -\frac{q}{2k}x^2 + \frac{q \cdot 2R}{k} + \frac{q \cdot 2R}{h} + T_\infty$$

Thus, the temperature difference between two points (x=0 and x=2R) is

$$\Delta T = T(2R)\text{-}T(0) = \frac{2q}{k} \cdot R^2$$

Then the mean temperature gradient is $\quad \frac{\Delta T}{2R} = \frac{q \cdot R}{k}$

Thus, we obtain the thickness increment between x=0 and x=2R is

$$\Delta = \Delta T \cdot H \cdot \alpha = \alpha \cdot H \cdot \beta \cdot P \cdot 2R^2/k$$

In the equation, H is lens thickness; α is the coefficient of thermal expansion; the corresponding maladjustment angle is Θ; and P is the laser power density. $\quad \theta = \frac{1}{2} \cdot \Delta \cdot /2R = \frac{1}{2} \cdot \frac{\alpha \cdot H \cdot \beta \cdot P \cdot R}{k}$

The above equation is derived with oversimplification. After numerical calculations of some typical parameters, we discover that the main cause of the resulting value falling in the larger side of the range by 30 to 50 percent is due to the error made in assuming that no heat conduction occurs in other directions. Therefore, we consider that it may be possible to carry out appropriate coefficient simulation on the basis of the above-mentioned equations. $\theta = \frac{1}{1.5} \cdot \frac{1}{2} \cdot \frac{\alpha \cdot H \cdot \beta \cdot P \cdot R}{k} = \frac{1}{3} \cdot \frac{\alpha \cdot H \cdot P \cdot R \cdot \beta}{k}$

To verify the equation, we find by measuring that $\beta = 0.08 cm^{-1}$. From the above equation, we obtain

when $P = 1200\overline{W}/\pi R^2$, $\theta = 3.7 mrad$.

In the experimental result, when the output power is 1200W, $\theta = 5 mrad$. Thus, the theory and experiment are in approximate agreement..

IV. Conclusion

Based on experimental phenomena, we find that unsymmetric thermally-induced optical distortion can induce the phenomenon of optical-cavity maladjustment. This phenomenon was illustrated in a preliminary theoretical treatment. These results have certain practical significance. In other words, when designing a laser output lens system, the problem of uniform cooling should be carefully considered.

The paper was received for publication on 24 November 1993.

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